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TREND ANALYSIS OF LAKE PARKER STAGE AND RELATION TO VARIOUS HYDROLOGIC FACTORS, 1950-86, LAKELAND, FLORIDA

U.S. GEOLOGICAL SURVEY
WATER-RESOURCES INVESTIGATIONS REPORT 89-4037

Prepared in cooperation with the
CITY OF LAKELAND, FLORIDA

ilable

CONVERSION FACTORS

The inch-pound units used in this report may be converted to metric (International System) units by the following factors:

Multiply inch-pound unit	By	To obtain metric unit
inch (in.)	25.4	millimeter (mm)
inch per year (in/yr)	25.4	millimeter per year (mm/yr)
foot (ft)	0.3048	meter (m)
foot per year (ft/yr)	0.3048	meter per year (m/yr)
mile (mi)	1.609	kilometer (km)
acre	0.4047	hectare (ha)
million gallons per day (Mgal/d)	0.4381	cubic meter per second (m^3/s)
million gallons per day per year [(Mgal/d)/yr]	0.4381	cubic meter per second per year [(m^3/s)/yr]
square mile (mi^2)	2.590	square kilometer (km^2)

Sea level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)--a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called "Sea Level Datum of 1929."

Additional Abbreviations

NWS = National Weather Service
ROMP = Regional Observation and Monitor-Well Program

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Water-Resources Investigations Report 89-4037

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Tallahassee, Florida
1989

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CONTENTS

	Page
Abstract	1
Introduction	1
Purpose and scope	1
Methods of analyses	3
Trend analyses	5
Kendall tau test	5
Regression analyses	9
Relation of Lake Parker stage to climate, pumpage, and ground-water levels	11
Dry-season change in lake stage	11
Monthly change in lake stage	15
Summary	17
References	19

ILLUSTRATIONS

Figure	Page
1. Map showing location of Lake Parker and data-collection sites	2
2-9. Graphs showing:	
2. Month-end stage of Lake Parker, 1950-86	3
3. Annual maximum, mean, and minimum stages of Lake Parker, 1950-86	6
4. Value of Kendall tau test parameter of Lake Parker annual minimum stages for periods ending in 1986	8
5. Value of Kendall tau test parameter of Lake Parker annual minimum stages for periods beginning in 1950	9
6. Annual rainfall at Lakeland (1950-86) and annual pan evaporation at Lake Alfred (1966-86)	10
7. Month-end stage at Lake Howard, Lake Hamilton, Lake Mariana, and Crooked Lake, 1950-86	12
8. Month-end water levels at ROMP well 60, Tampa well 15, Lake Alfred deep well, and Sanlon Ranch well, 1961-86	13
9. Ground-water pumpage by the city of Lakeland, 1956-86	14

TABLES

Table	Page
1. Data-collection sites	4
2. Summary of Kendall tau test analyses on Lake Parker stage variables	7
3. Summary of Kendall tau test analyses on rainfall, pan evaporation, lake stages, ground-water levels, and pumpage	11
4. Summary of simple linear-regression analyses of Lake Parker stage variables as a function of time	15
5. Summary of simple linear regression of rainfall, pan evaporation, lake stages, ground-water levels, and pumpage as a function of time	16
6. Computation of change in Lake Parker stage by equation 2 for four selected months	18

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ABSTRACT

Kendall's tau and linear-regression techniques were used to determine if statistically significant ($\alpha = 0.10$) long-term trends for period of record exist for Lake Parker stage data or for four other area lakes, four ground-water sites, four rainfall sites, Lakeland public-supply pumpage, and pan evaporation. Findings were consistent between the two analytical methods.

There were no statistically significant long-term trends indicated for seasonal or annual mean daily stage data at Lake Parker. Statistically significant Kendall tau slope estimators were detected for pan evaporation (+0.45 inch per year), Lakeland well-field annual average pumpage (+0.56 million gallons per day per year), and one ground-water site (+0.48 foot per year). Statistically significant negative slope estimators were indicated for three other lakes (-0.03 to -0.27 foot per year) and one ground-water site (-0.25 foot per year). Rainfall indicated no long-term trends.

The seasonal change in Lake Parker stage from November to May was related by multiple linear regression to changes in ground-water levels, rainfall, and pumpage for the same time period. The regression coefficient of determination was 0.90, and the standard error was 0.24 foot. Monthly changes in average lake stage for November through May were related to evaporation, rainfall, and ground-water levels with a regression coefficient of determination of 0.67 and standard error of 0.14 foot.

INTRODUCTION

Lake Parker is a 2,291-acre natural lake within the city limits of Lakeland in Polk County, Fla. (fig. 1). In addition to its esthetic value, the lake is used for recreation and for cooling water for two city-owned electrical generating plants. The mean lake stage for 1949-86 was 129.88 feet above sea level. Approximately 2 miles west of the lake is the city's Northwest well field, permitted to pump an average of 28.3 Mgal/d from the underlying Upper Floridan aquifer. Polk County's two largest industries, phosphate mining and related chemical processing, used about 117 Mgal/d of water from the same aquifer system in 1985 (Stieglitz, 1986).

The confining layer between the surficial aquifer and the Upper Floridan aquifer varies from 50 to 100 feet thick in the Lakeland area (Buono and others, 1979). Water levels in the Upper Floridan aquifer wells in the Lakeland area have fluctuated between 30 to 60 feet below water levels in the lakes; hence, there is the possibility for downward leakage.

In July 1985, the mean daily stage of Lake Parker fell to 127.62 feet above sea level, the lowest elevation since stage records began in 1949 (fig. 2). On June 8, 1986, the mean daily stage declined to 127.02 feet above sea level and threatened to drop below the cooling-water intakes for the power-generating plants. A sinkhole formed near the western shore of Lake Parker on May 17, 1986, and was reported to have collapsed, forming a natural plug by June 21, 1986 (Dyer, Riddle, Mills and Precourt, Inc., 1986). The city utilities department and local citizens, however, became concerned that Lake Parker might be undergoing a long-term declining trend in stage, possibly related to ground-water pumpage and resultant lowered ground-water levels.

The U.S. Geological Survey has collected weekly stage readings for Lake Parker from May 1949 to June 1954 and has collected continuous stage recordings from 1954 through the present (1988). In November 1986, the U.S. Geological Survey, in cooperation with the Lakeland Department of Electric and Water Utilities, began a study of analyzing existing hydrologic data to determine the relation of lake stages to other hydrologic variables and to determine if lake stages were in a long-term declining trend. This report describes and presents results of those analyses based on data from May 1949 through the 1986 calendar year.

Purpose and Scope

The purpose of this report is to analyze existing data on lake stage, ground-water levels, public-supply pumpage, and climatic data to determine:

1. If Lake Parker stage is in a long-term declining trend;
2. If any detected trends are occurring only at Lake Parker or are typical of regional trends in lake stage, rainfall, ground-water levels, and evaporation; and

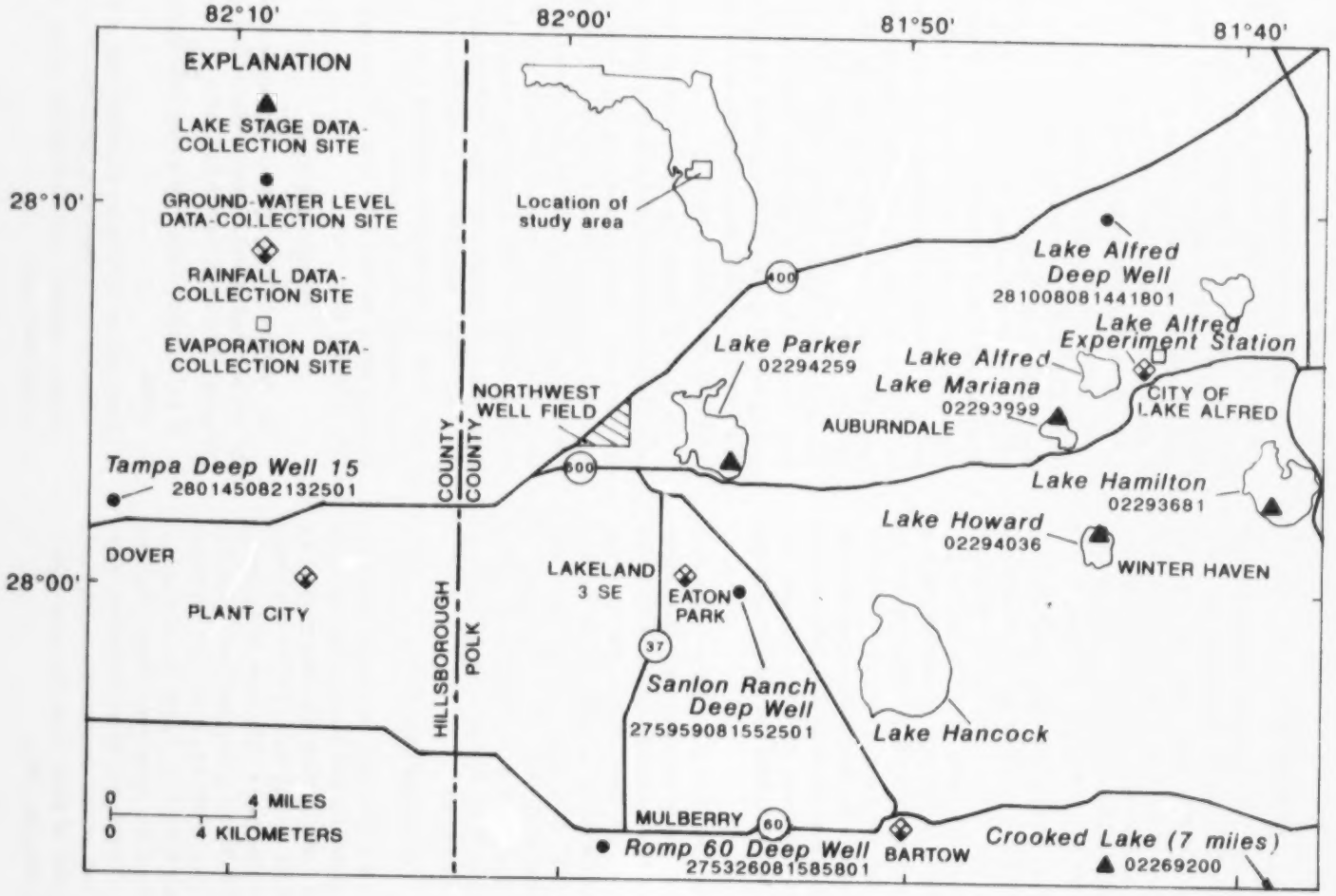

Figure 1.—Location of Lake Parker and data-collection sites.

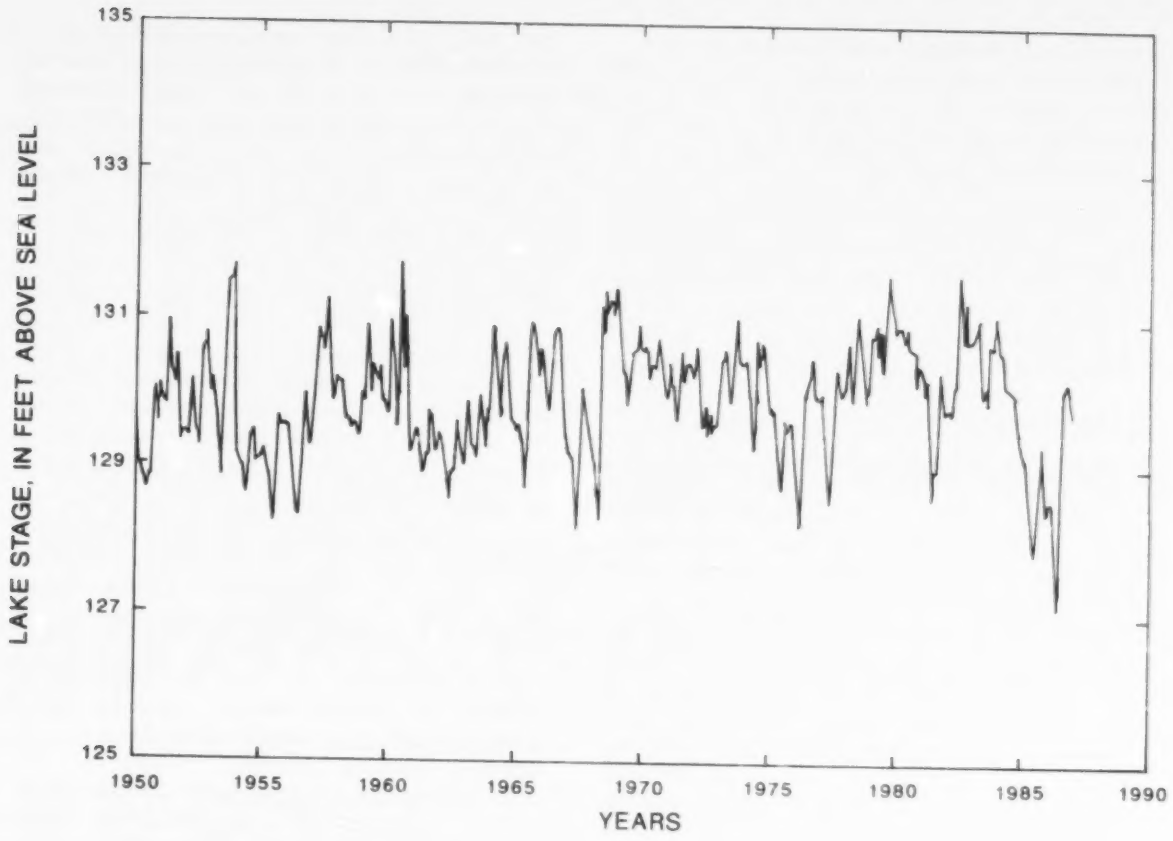

Figure 2.—Month-end stage of Lake Parker, 1950-86.

3. How Lake Parker stage is related to rainfall, evaporation, ground-water levels, and public-supply ground-water pumpage.

The scope of the investigation included statistical analyses of hydrologic data collected at Lake Parker and other sites within a 30-mile radius of Lake Parker. One ground-water site was in Hillsborough County, just west of the Polk County line, and all other data were from within Polk County (fig. 1).

In addition to stage data at Lake Parker, lake stage data from four other lakes were evaluated—Lake Howard, Lake Hamilton, Lake Mariana, and Crooked Lake. These lakes were chosen from among many lakes in the area because of proximity, length of record, and frequency of data collection. All have stage data for 1950-86. Four ground-water sites, all monitoring the Upper Floridan aquifer, were selected because of long periods of record to provide information on regional ground-water levels and fluctuations. Rainfall data from four National Weather Service (NWS) stations and pan evaporation data from the NWS station at Lake Alfred experiment station were included in the analyses. Data on monthly pumpage of ground water were supplied by the city of Lakeland. Information on all data-collection sites is listed in table 1.

Methods of Analyses

The primary statistical approach in this report for determining if long-term trends exist in the hydrologic data is the Kendall tau test (Kendall, 1975). This is a nonparametric, rank-correlation analysis that compares each value in a time series with all subsequent values. If no trends exist in the data, the number of larger subsequent values should approximately equal the number of smaller subsequent values, and the value of the Kendall tau parameter will be zero or close to zero. If a positive trend exists in the data, a significantly greater number of larger subsequent values will be found within the group of comparisons, and the resultant calculated value of the Kendall tau parameter will be positive with a magnitude between 0 and 1. A Kendall tau value of +1.0 indicates a

Table 1.—*Data-collection sites*

[mi^2, square mile]

Lakes

Site name	Site number	Latitude-longitude	Surface area (acres)	Drainage area (mi^2)	Stage, in feet above sea level: Maximum	Mean	Minimum	Period of record	Frequency of observation
Lake Parker at Lakeland	02294259	28°02'59" 081°55'22"	2,291	23.6	131.91	129.88	127.02	1949-54 1955-86	Weekly Continuous
Lake Howard at Winter Haven	02294036	28°00'58" 081°44'22"	634	12.8	133.19	130.81	128.28	1945-63 1963-86	Weekly Continuous
Lake Hamilton near Lake Hamilton	02293681	28°01'54" 081°38'42"	2,170	20.5	124.34	119.83	116.89	1945-63 1963-86	Weekly Continuous
Lake Mariana near Auburndale	02293999	28°04'10" 081°45'20"	500	2.85	138.58	136.03	133.90	1946-86	Weekly
Crooked Lake near Babson Park	02269200	27°49'39" 081°33'12"	5,533	31.3	124.10	116.40	107.65	1945-86	Weekly

Ground-water sites

Site name	Site number	Latitude-longitude	Depth, in feet: Cased	Total	Aquifer monitored	Elevation, in feet above sea level: Maximum	Mean	Minimum	Period of record	Frequency of observation
ROMP 60 deep well at Mulberry	275326081585801	27°53'26" 081°58'58"	237	710	Floridan	87.07	57.86	25.90	1955-59 1960-61 1961-86	Bimonthly Annually Continuous
Tampa deep well 15 near Dover	280145082132501	28°01'45" 082°13'25"	67	413	Floridan	71.91	62.93	46.90	1958-86	Continuous
Lake Alfred deep well near Lake Alfred	281008081441801	28°10'08" 081°44'18"	102	425	Floridan	131.07	126.93	119.85	1959-60 1960-86	Monthly Continuous
Sanlon Ranch deep well near Eaton Park	275959081552501	27°59'59" 081°55'25"	293	1,220	Floridan	98.70	85.38	66.38	1970-86	Continuous

Climatic sites

Site name	Operated by	Latitude-longitude	Data type	Range measured, in inches: Maximum	Mean	Minimum	Period of record	Frequency of observation
Bartow	National Climatic Data Center (NCDC)	27°54' 081°51'	Rainfall, annual total	83.44	52.73	35.18	1950-86	Daily
Lakeland 3 SE	NCDC	28°01' 081°55'	Rainfall, annual total	70.24	48.28	35.83	1950-86	Daily
Lake Alfred Experiment Station	University of Florida/NCDC	28°06' 081°43'	Pan evaporation, annual total	86.25	72.03	66.76	1966-86	Daily
			Rainfall, annual total	76.57	50.54	35.66	1950-86	Daily
Plant City	NCDC	28°01' 082°08'	Rainfall, annual total	86.68	53.35	32.96	1950-86	Daily

Public-supply pumpage

Site name	Operated by	Latitude-longitude	Data type	Range measured, average million gallons per day: Maximum	Mean	Minimum	Period of record
Lakeland public-supply pumpage	City of Lakeland	28°04' 081°59'	Ground-water pumpage, monthly average	34.051	14.881	4.452	1956-86

nonoscillating, increasing trend in the data. For negative trends, the magnitude of the Kendall tau parameter ranges from -1.0 to 0.0. A significance level of 10 percent was chosen as the criterion to state that a trend is statistically significant ($p < 0.10$, where p is the attained significance level, the probability that an indicated trend resulted in a chance arrangement of the data rather than an actual trend in the data). The Kendall tau test was performed for annual and seasonal values of stage, ground-water levels, rainfall, evaporation, and pumpage. The magnitude of an indicated trend is determined on the basis of the Kendall slope estimator (Hirsch and others, 1982). The slope estimator is the median value of all pairwise slopes within a time-series data set.

Simple linear-regression analysis is used as an alternative method for determining the existence of data trends, as well as the principal method for determining the relation of the change in Lake Parker stage to ground-water levels, pumpage, and climatic data. For determination of trends, the hydrologic data are regressed separately against time. If the coefficient of the explanatory variable, time, is positive and is statistically significant, the data indicate an increasing trend at the given significance level. The converse is true for a negative, statistically significant coefficient of time in the linear-regression equation. The same significance level used in the Kendall tau analysis (10 percent) is used to determine if the coefficient of time is significantly different from zero.

Multiple linear regressions are developed to indicate the degree of relation of change in lake stage to other hydrologic data. Coefficient of determination (multiple R^2, adjusted for sample size and the number of explanatory variables) and standard error of estimate of the regression equation are used to determine, respectively, the degree to which an explanatory variable affects the variation of the dependent variable and the reliability of estimates of the regression equation.

The standard error of the regression is a measure of the reliability of the regression relation. That is, approximately 67 percent of values estimated by the regression are within one standard error of the measured value of the dependent variable, assuming normality of the residuals of the regression. The attained significance level presented in tables 2 through 5 is the percentage chance that the indicated coefficient of the explanatory variable could have occurred by chance alone. A significance level of 10 percent was chosen as the criterion for accepting a regression coefficient as significant.

It should be noted that a regression equation and the resultant statistical descriptors indicate the degree of association between the data set of the dependent variable and the data set(s) of explanatory variables and do not necessarily describe a cause-and-effect relation between the dependent and explanatory variables. Rigorous discussion of the methods of regression equation formulation, significance, and use can be found in most statistical textbooks (Riggs, 1968).

TREND ANALYSES

Kendall Tau Test

Hydrologic data, especially daily or monthly means, tend to be serially correlated, and these data may need to be analyzed by some modification of the Kendall tau test that corrects the significance level for the effects of serial correlation (Hirsch and Slack, 1984). On the other hand, annual data tend to be independent unless there is a trend; therefore, the tests for serial correlation were not applied to annual data.

The Kendall tau test was first applied to annual stage data for Lake Parker. Figure 3 shows annual maximum, mean, and minimum of the daily mean stages for Lake Parker for 1950-86. Results of the Kendall tau test, using the entire 37-year period of record, are presented in table 2. All three annual stage values for Lake Parker yield a positive value of the Kendall tau parameter, but none of the values is of sufficient magnitude to be significant at the 10-percent level. The analyses of annual values of stage indicate no significant trends for Lake Parker. Even though record minimum stages were observed in 1985-86, it should be noted that annual minimum stages of Lake Parker have not exhibited a significant downward trend for the entire period of record, 1950-86.

The findings and significance of any trend analysis method sometimes depend on the period of record of the time-series data set. Choosing different periods for analysis may indicate an increasing trend for one period and a decreasing trend for another period of the same time series. Short-term trends may be opposite of long-term trends. For the period 1950-86, analyses of Lake Parker stage data indicated no significant trends. Additional analyses of stage data were conducted to allow comparison of analyses of Lake Parker data with other data having different periods of record and to show shorter trends in the stage data.

Two time series of Kendall tau test parameters were constructed using annual minimum stage data;

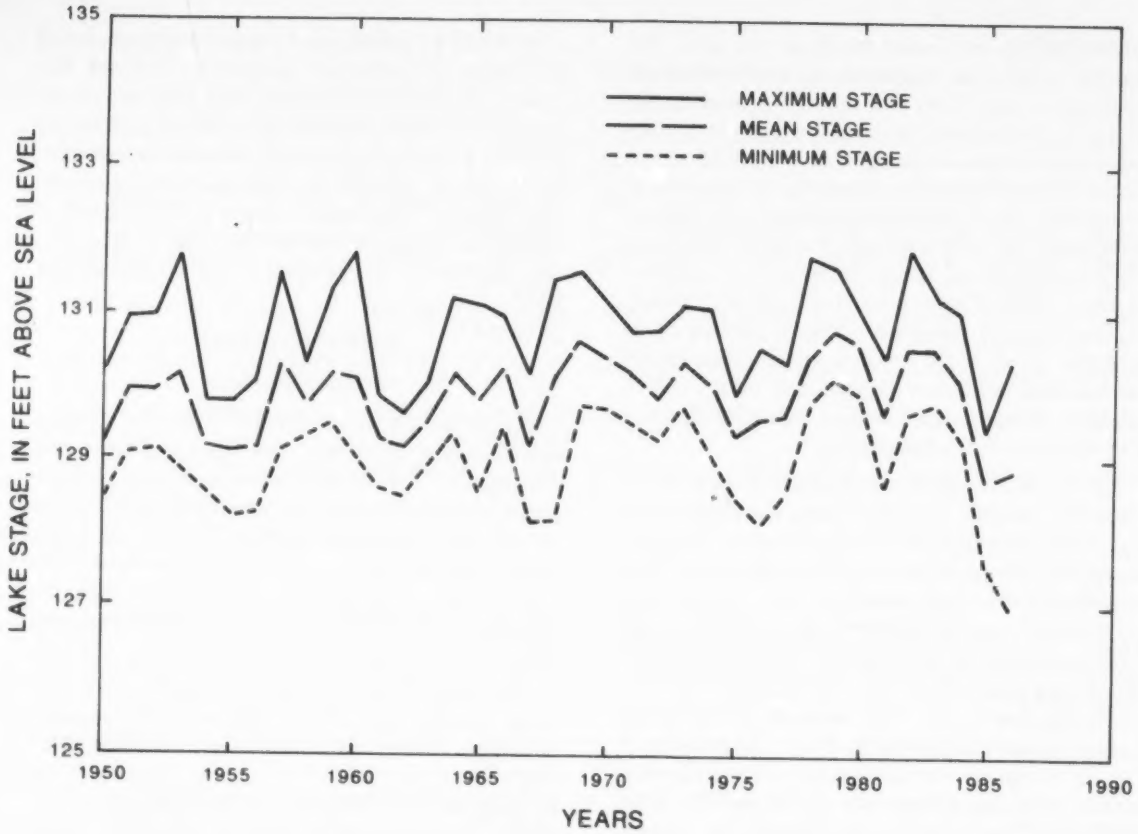

Figure 3.—Annual maximum, mean, and minimum stages of Lake Parker, 1950-86.

one is based on different starting years for the data, and the second is based on a different ending year for data beginning in 1950. Figure 4 shows values of the Kendall tau test parameter for annual minimum stages looking back from 1986 to a given starting year of data collection. The dashed lines represent the value of tau necessary for the slope estimator to be significant at the 10-percent level for different time periods. For example, if data collection had started in 1980 instead of 1950, the calculated value of tau for 1980-86 is -0.6190, indicating a declining trend in stage data that is significant at the 5.1-percent level. This figure illustrates how apparent or short-term trends may occur within a longer period of record used in the analysis. It is also useful to compare indicated trends at Lake Parker in 1986 to trends indicated for other sites that have a shorter period of record. Figure 5 illustrates how the Kendall tau parameter has varied since 1950. If tau had been calculated in 1980 using data for 1950-80, the value of tau would have been +0.2495, indicating an increasing trend in Lake Parker stage significant at the 5.1-percent level. The tau value for 1950 in figure 4 corresponds with the tau value for 1986 in figure 5—both use data for 1950-86.

Following the analysis of annual stage values, analyses were conducted on low-stage duration data determined for each year of the 1955-86 period. (Stage readings prior to 1955 were incomplete and not appropriate for inclusion in a duration analysis.) These values indicate the lowest average stages that were recorded for the indicated number of consecutive days for each year. (The 1-day low stage is equivalent to the annual minimum mean daily stage.) Depending on stage fluctuation patterns, lake stages for a duration interval could show a downward trend even though annual minimum stages do not. Analyses for low-stage data were conducted because primary concern at Lake Parker resulted from low stages rather than maximum stages.

Results of Kendall tau analyses for the 1-, 3-, 7-, 14-, 30-, 60-, 90-, 120-, and 183-day low-stage duration

Table 2.—*Summary of Kendall tau test analyses on Lake Parker stage variables*

[ft/yr, feet per year]

Variable	Period	Tau value	Slope estimator (ft/yr)	Attained significance level
Annual mean	1950-86	+0.1877	+0.01	0.1048
Annual minimum	1950-86	+ .1486	+ .01	.1998
Annual maximum	1950-86	+ .0856	+ .01	.4638
Low-stage duration of:				
1-day	1955-86	+ .1190	+ .01	.3467
3-day	1955-86	+ .1230	+ .01	.3304
7-day	1955-86	+ .1230	+ .01	.3302
14-day	1955-86	+ .1149	+ .01	.3638
30-day	1955-86	+ .1129	+ .01	.3722
60-day	1955-86	+ .1048	+ .01	.4081
90-day	1955-86	+ .0907	+ .01	.4754
120-day	1955-86	+ .0786	+ .01	.5376
183-day	1955-86	+ .1129	+ .01	.3722
Dry season (November-May) mean	1951-86	+ .1772	+ .01	.1261
Wet season (June-October) mean	1950-86	+ .1381	+ .01	.2343

values for 1955-86 also are presented in table 2. As shown with annual values of Lake Parker stage, values of the Kendall tau parameter for all low-stage duration values are positive, but none is significant at the 10-percent level. No trends are indicated.

Seasonal analyses were performed next using mean stage for a designated "dry season" and "wet season." The dry season was chosen as November through May and the wet season as June through October. Monthly rainfall for the wet-season period averaged more than twice the monthly dry-season average during 1950-86. Changes in flow to or from the lake possibly could result in seasonal fluctuations that may not be detected by annual stage analysis or low-stage duration periods, which do not occur during a set period each year.

Results of Kendall tau tests for seasonal means also are presented in table 2. The Kendall tau parameter is positive for both seasonal analyses, but, once again, neither indicates a trend that is significant at the 10-percent level.

The next to last column of table 2 is the Kendall slope estimator and is listed only for comparison with Kendall tau analyses on other data. Because none of the Lake Parker stage variables indicated a significant trend, the slope estimator is—except for comparison purposes—of no hydrologic significance.

Rainfall and evaporation are the largest sources of inflow and outflow of water to Lake Parker. Rainfall at the Lakeland NWS station averaged 48.28 in/yr for 1950-86. The closest NWS pan evaporation site to Lake Parker is at Lake Alfred Experiment Station, 12 miles east of the lake, where pan evaporation has averaged 72.03 in/yr since the beginning of data collection in 1966 (fig. 6).

Annual rainfall data from the four closest NWS rainfall stations were analyzed by the Kendall tau test for the period 1950-86, coincident with the period of stage record at Lake Parker. Pan evaporation data from the Lake Alfred Experiment Station for 1966-86 also were analyzed. Results of the analyses are presented in table 3. There are no trends indicated in the 37 years of rainfall data from the four sites. The value of the Kendall tau parameter for pan evaporation (+0.4762) indicates an increasing trend that is significant at the 1-percent level. The slope estimator indicates that measured pan evaporation at Lake Alfred Experiment Station changed at a median rate of +0.45 in/yr for 1966-86. It is obvious from the graph of annual pan evaporation in figure 6 that there was no apparent increase in pan evaporation in the period 1966-79, but there was a noticeably greater annual rate from 1980 to 1986. The slope estimator of annual change for 1966-79 is -0.03, whereas the slope

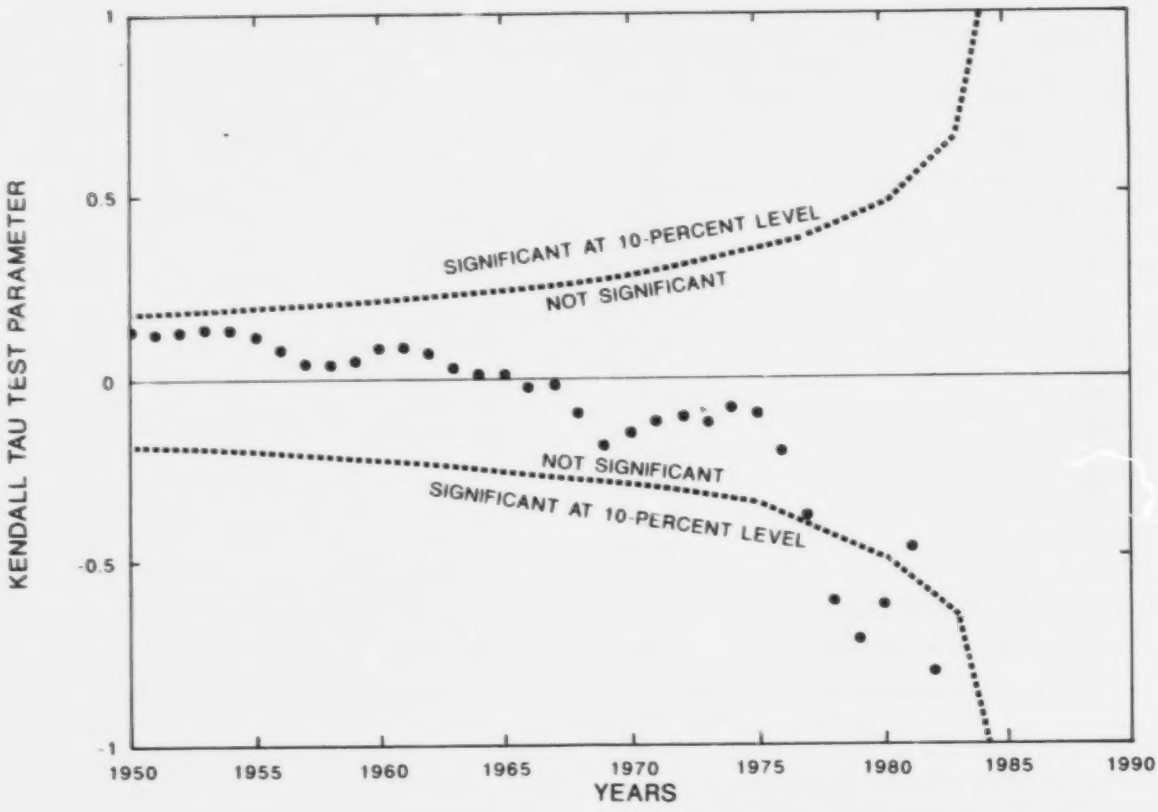

Figure 4. – Value of Kendall tau test parameter of Lake Parker annual minimum stages for periods ending in 1986.

estimator for 1980-86 is +1.65. This corresponds to the short-term statistically significant negative slope estimator for 1980-86 annual minimum stage at Lake Parker (fig. 4).

Four other lakes were chosen for analyses based on proximity and stage record coincident with Lake Parker. Hydrographs of Lake Howard, Lake Hamilton, Lake Mariana (all in the Peace River drainage area), and Crooked Lake (in the Kissimmee River drainage area) are shown in figure 7. Results of Kendall tau analyses are presented in table 3. Lakes Howard, Hamilton, and Crooked all show significant downward trends in stage, with slope estimators ranging from -0.02 ft/yr at Lake Howard to -0.27 ft/yr at Crooked Lake. The downward trend in stage at Crooked Lake is obvious in the hydrograph in figure 7.

Four ground-water sites were evaluated to determine if regional long-term trends were exhibited in water levels of the Upper Floridan aquifer (fig. 8). There were no ground-water sites in the area with continuous data extending back to 1950 and no long-term sites adjacent to Lake Parker. Kendall tau analysis of water levels in ROMP well 60, Tampa well 15, and Lake Alfred deep well indicate decreasing trends at various levels of significance (table 3). The positive trend indicated at the fourth site, Sanlon Ranch well, is significant at the 10-percent level and may result more from the shorter period of record (1970-86) at this site than from a difference between water levels here and at the other wells. If only data for post-1970 are analyzed for the other three sites, Kendall tau tests indicate significant positive trends instead of the negative trends indicated for 1961-86 data. Based on records from a discontinued ground-water site near Sanlon Ranch well, water levels in the Upper Floridan aquifer in the area decreased more than 15 feet during 1960-70.

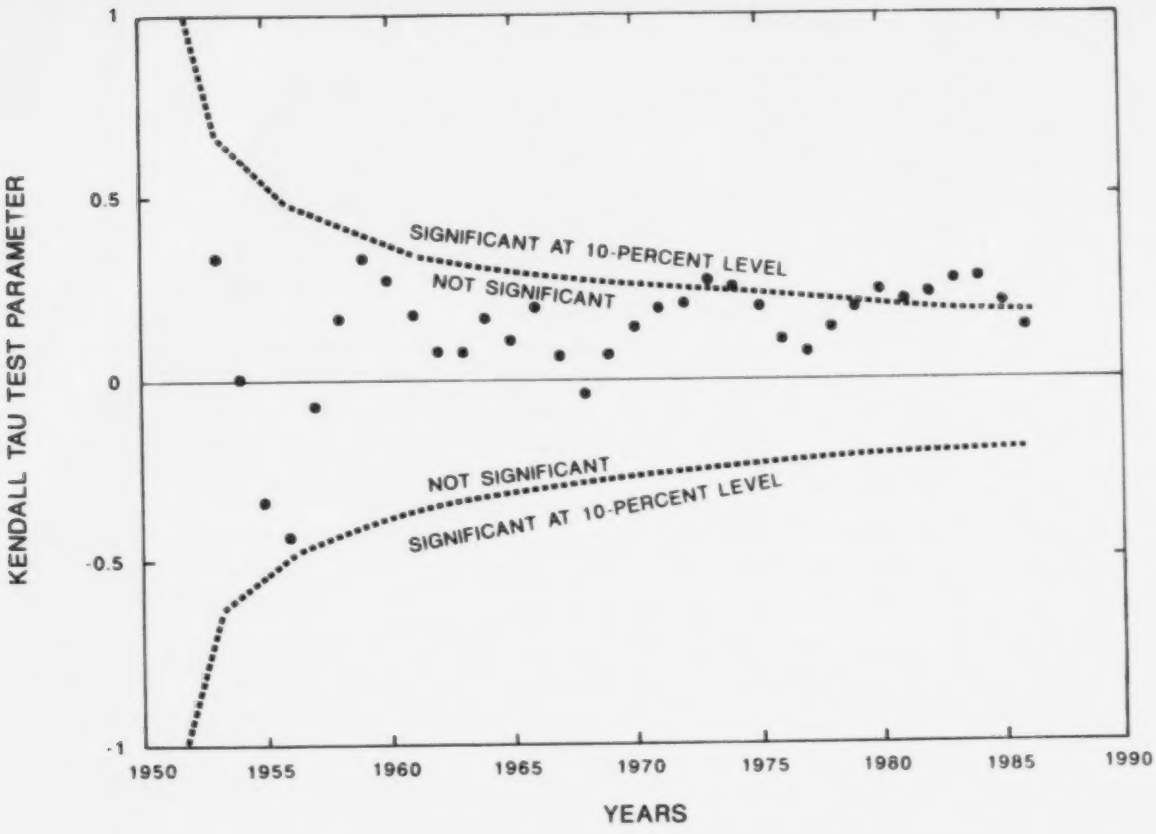

Figure 5. – Value of Kendall tau test parameter of Lake Parker annual minimum stages for periods beginning in 1950.

The city of Lakeland held permits in 1986 to pump an average of 28.3 Mgal/d from the Northwest well field about 2.5 miles west of Lake Parker. Original ground-water withdrawals by the city were from widely scattered wells in an area centered about 2.5 miles southwest of Lake Parker (Dyer, Riddle, Mills, and Precourt, Inc., 1986). Pumpage from these wells increased from 6.6 Mgal/d in 1956 to 21.1 Mgal/d in 1982 (fig. 9). Withdrawals from the Northwest well field began in April 1983. Average pumpage from the well field increased from 20.8 Mgal/d in 1983 to 23.9 Mgal/d in 1986. Monthly average pumpage in 1986 ranged from 19.9 Mgal/d in January to 33.5 Mgal/d in May. The Kendall tau test for annual average pumpage yields a tau value of +0.9183 and is significant at the 0.01-percent level. The slope estimator indicates an increase in pumpage of +0.56 (Mgal/d)/yr.

Regression Analyses

Regression analyses of stage at Lake Parker were conducted as a verification of Kendall tau analyses and to indicate the relation between lake stage and other hydrologic factors. Regression equations of different stage variables of Lake Parker as a function of time (calendar years) are presented in table 4. Stage variables in this table are the same as those presented in table 2 that show the results of Kendall tau analysis, allowing a comparison between the two methods of trend analysis. With YR (calendar year-1900) as the explanatory variable in the regression equations, the coefficient of YR indicates the rate of change of the dependent variable (stage) with time. A negative coefficient would indicate a decline in stage with time or a negative trend. The coefficient of determination (R^2) indicates the proportion of variance in the stage variable that is explained by the dependent variable, YR.

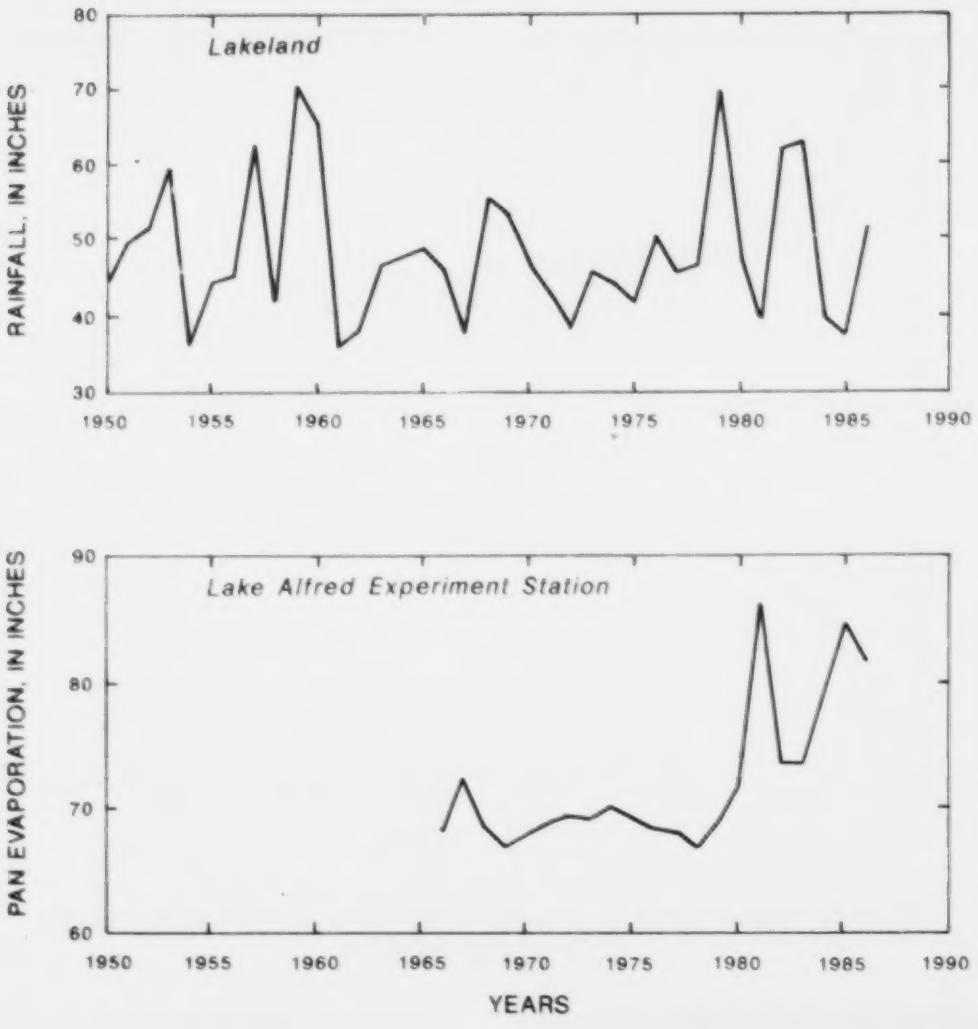

Figure 6. – Annual rainfall at Lakeland (1950-86) and annual pan evaporation at Lake Alfred (1966-86).

None of the significance levels shown in table 4 is within the 10-percent criterion. This indicates, as did the findings of Kendall tau analysis in table 2, that there are no statistically significant trends indicated in the Lake Parker stage variables. Generally, the equations would not be presented if not significant, but it is considered informative to list them here. Although attained significance levels in table 4 are generally higher than in table 2, there are no discrepancies in findings between Kendall tau analysis and regression analysis of Lake Parker stage variables.

Regression equations of other hydrologic variables as a function of time are presented in table 5 following the same order as given in the Kendall tau analysis in table 3. All of the data sets that indicate significant trends using Kendall analysis yield the same results for the regression analyses presented in table 5. For example, water levels at Sanlon Ranch well for 1970-86 indicate an increase of 0.48 ft/yr in Kendall analysis and an increase of 0.489 ft/yr from the coefficient of YR (slope of the regression equation). Both analyses indicate that public-supply pumpage increased at an average rate of 0.56 (Mgal/d)/yr during 1956-86. In summary, statistically significant declining trends were indicated from water-level data at four sites: Lake Howard, Lake Hamilton, Crooked Lake, and Tampa deep well 15. Statistically significant increasing trends were determined for Lake Alfred Experiment Station pan evaporation, Sanlon Ranch well water levels, and public-supply pumpage.

Table 3. – *Summary of Kendall tau test analyses on rainfall, pan evaporation, lake stages, ground-water levels, and pumpage*

[in/yr, inch per year; ft/yr, foot per year; (Mgal/d)/yr, million gallons per day per year]

Data	Period	Tau value	Slope estimator	Attained significance level
Lakeland annual rainfall	1950-86	-0.0075	-0.01 in/yr	0.9584
Bartow annual rainfall	1950-86	- .1441	- .21 in/yr	.2140
Lake Alfred annual rainfall	1950-86	- .1502	- .23 in/yr	.1954
Plant City annual rainfall	1950-86	- .0721	- .09 in/yr	.5387
Lake Alfred annual pan evaporation	1966-86	+ .4762	+ .45 in/yr	.0030
Lake Howard				
Annual mean stage	1950-86	- .2387	- .03 ft/yr	.0386
Annual minimum stage	1950-86	- .2868	- .03 ft/yr	.0130
Annual maximum stage	1950-86	- .2842	- .02 ft/yr	.0752
Lake Mariana				
Annual mean stage	1950-86	+ .0060	0 ft/yr	.9686
Annual minimum stage	1950-86	+ .0405	0 ft/yr	.7338
Annual maximum stage	1950-86	- .0285	0 ft/yr	.8037
Lake Hamilton				
Annual mean stage	1950-75, 1978-86	- .2975	- .06 ft/yr	.0120
Annual minimum stage	1950-75, 1978-86	- .2992	- .05 ft/yr	.0122
Annual maximum stage	1950-75, 1978-86	- .2756	- .06 ft/yr	.0150
Crooked Lake annual mean stage	1950-86	- .7132	- .27 ft/yr	.0001
ROMP 60 deep well annual mean	1961-86	- .2062	- .35 ft/yr	.1457
Tampa well 15 annual mean	1961-86	- .5670	- .25 ft/yr	.0001
Lake Alfred deep well annual mean	1961-86	- .1385	- .02 ft/yr	.3321
Sanlon Ranch deep well annual mean	1970-86	+ .3235	+ .48 ft/yr	.0766
Lakeland public-supply pumpage annual mean	1956-86	+ .9183	+ .56 (Mgal/d)/yr	.0001

RELATION OF LAKE PARKER STAGE TO CLIMATE, PUMPAGE, AND GROUND-WATER LEVELS

Although regression analyses indicate association between dependent and explanatory variables rather than direct cause and effect, the best results were obtained by using the four explanatory variables that may affect lake stage directly or indirectly – rainfall, pan evaporation, ground-water levels, and pumpage. Dry-season analyses generally provided more consistent results than did wet-season or annual data (which include wet-season periods) because: (1) dry-season rainfall is more uniform than wet-season rainfall; (2) errors in measurement and distribution of rainfall are less significant with lower rainfall; (3) inflow and outflow to the lake, unmeasured and unrepresented in this analysis, generally occur during the wet season; and (4) the effects of pumpage or ground-water levels on lake stages are more pronounced, less masked, than during the wet season. Change-in-stage data can be more closely related to quantities such as rainfall than can mean stages, which are partly dependent on events occurring before the period of analysis.

Dry-Season Change in Lake Stage

The change in Lake Parker stage (1961-86) from November 1 to May 31 of the following year was

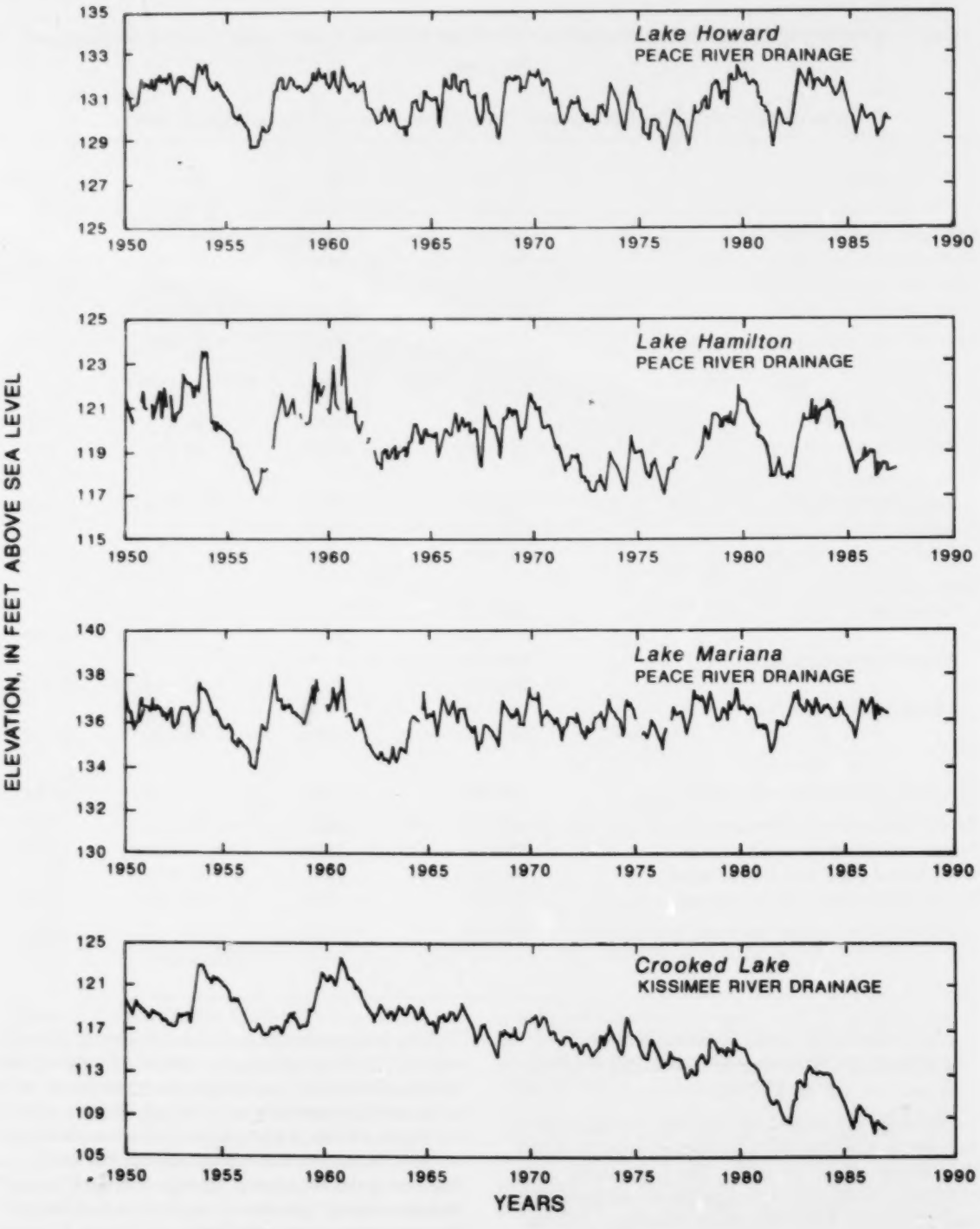

Figure 7.—Month-end stage at Lake Howard, Lake Hamilton, Lake Mariana, and Crooked Lake, 1950-86.

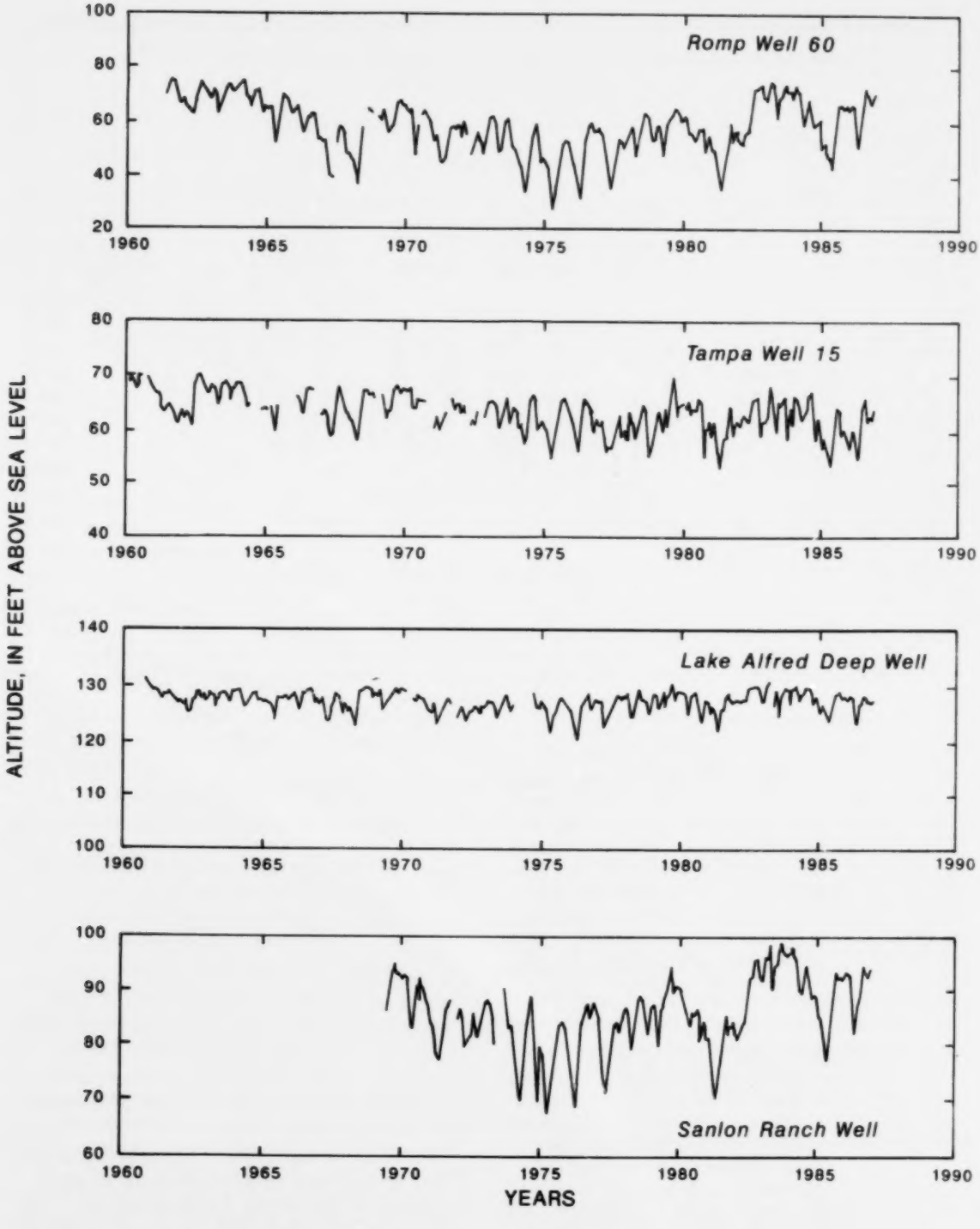

Figure 8. – **Month-end water levels at ROMP well 60, Tampa well 15, Lake Alfred deep well, and Sanlon Ranch Well, 1961-86.**

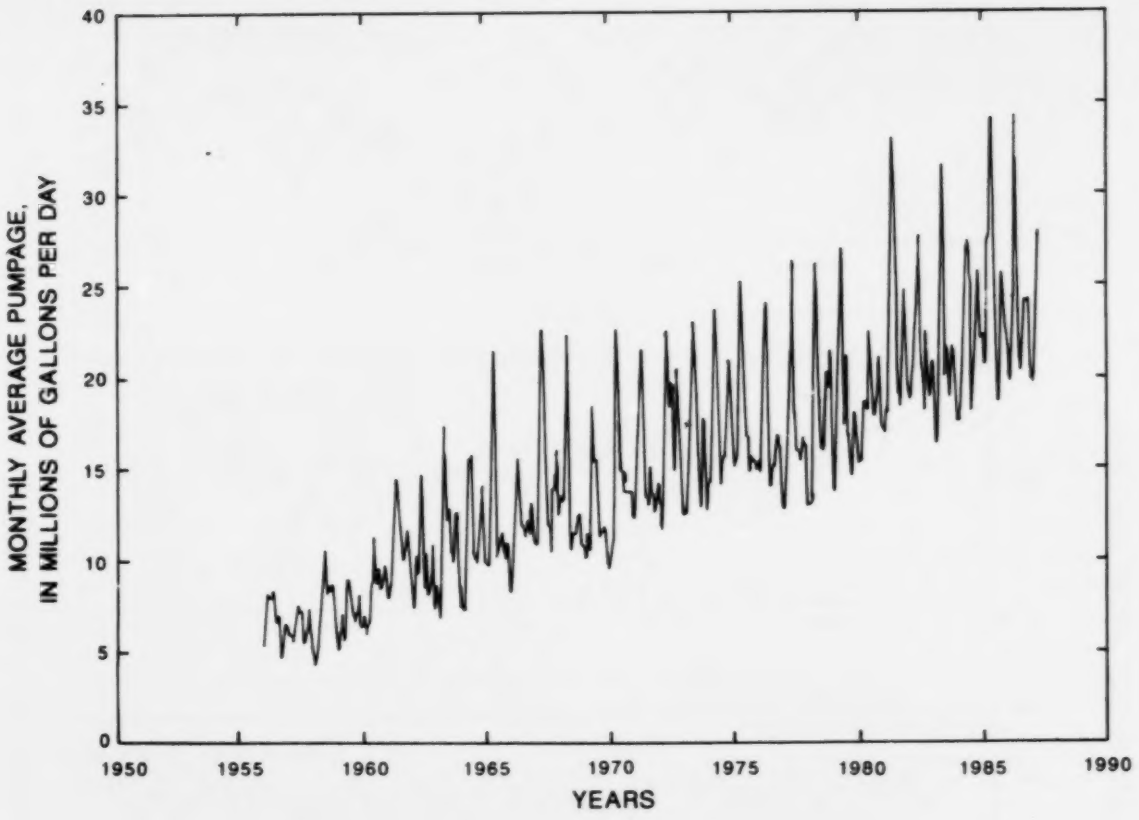

Figure 9.—Ground-water pumpage by the city of Lakeland, 1956-86.

related to climatic variables (rainfall, pan evaporation, pumpage, and ground-water levels) for the same time period. Equation 1 is the regression for the change in stage derived from dry-season data that had the highest R^2 and lowest standard error. The R^2 is 0.91 and the regression has a standard error of estimate of 0.24 foot.

$$DSTAGE = -0.256 + 0.144 \times D.GW + 0.463 \times RAIN - 0.00336 \times PUMP \quad (1)$$

where DSTAGE is the change in Lake Parker stage from November 1 to May 31 of the following year, in feet;

D.GW is the sum of change in water level in Lake Alfred deep well and one third of the change in ROMP 60 deep well from November 1 to May 31 of the following year, in feet;

RAIN is the total rainfall at the NWS gage in Lakeland for the months of November through May of the following year, in feet; and

PUMP is the sum of the monthly mean pumpage from the Lakeland well fields from November through May of the following year, in million gallons per day.

Pan evaporation was not significant at the10-percent level.

The change in water level in the Lake Alfred and ROMP 60 deep wells is representative of the regional fluctuation in the Upper Floridan aquifer. The Lakeland water-supply wells cause an additional drawdown superimposed on the regional change. A ground-water model used to simulate the average permitted well-field pumpage estimated about a 4-foot drawdown in the Upper Floridan and from

Table 4.—*Summary of simple linear-regression analyses of Lake Parker stage variables as a function of time*

[R^2 is coefficient of determination; STAGE is Lake Parker stage in feet above sea level; YR is calendar year - 1900]

Variable	Period	Regression equation	R^2	Standard error (feet)	Attained significance level
Annual mean	1950-86	STAGE = 0.010 x YR + 129.19	0.00	0.55	0.242
Annual minimum	1950-86	STAGE = 0.005 x YR + 128.64	.00	.71	.653
Annual maximum	1950-86	STAGE = 0.008 x YR + 130.24	.00	.70	.468
Low-stage duration of					
1-day	1955-86	STAGE = 0.00273 x YR + 128.80	.00	.75	.851
3-day	1955-86	STAGE = 0.00259 x YR + 128.83	.00	.76	.860
7-day	1955-86	STAGE = 0.00251 x YR + 128.86	.00	.76	.864
14-day	1955-86	STAGE = 0.00341 x YR + 128.83	.00	.76	.816
30-day	1955-86	STAGE = 0.00396 x YR + 128.86	.00	.76	.786
60-day	1955-86	STAGE = 0.00373 x YR + 128.98	.00	.74	.795
90-day	1955-86	STAGE = 0.00322 x YR + 129.12	.00	.73	.819
120-day	1955-86	STAGE = 0.00270 x YR + 129.25	.00	.72	.847
183-day	1955-86	STAGE = 0.00461 x YR + 129.28	.00	.68	.726
Dry season (November-May) mean	1950-86	STAGE = 0.0121 x YR + 129.00	.00	.59	.192
Wet season (June-October) mean	1950-86	STAGE = 0.00877 x YR + 129.36	.00	.65	.384

0.1- to 0.2-foot drawdown in the surficial aquifer under Lake Parker (Dyer, Riddle, Mills and Precourt, Inc., 1986).

The relative correlation of the explanatory variables to the dry-season change in lake stage can be evaluated for each variable from the t value and the probability level that the coefficient is not zero. These are as follows: DGW, t = 6.99 and $p > |t| = 0.0001$; RAIN, t = 3.39 and $p > |t| = 0.0031$; and PUMP, t = -2.09 and $p > |t| = 0.0500$.

Residuals range from -0.47 foot in 1966 to +0.43 foot in 1970. Regression analysis of the residuals indicate no significant slope with time. It is important to note that residuals for 1985 and 1986 dry-season change in stage from equation 1 are relatively small (+0.08 foot and -0.05 foot, respectively). Successive periods of record low stages occurred during each of these 2 years. The fact that the regression equation, using 1961-86 data, yields a predicted value close to the actual change in stage for these 2 years indicates that the dry-season declines were not anomalous to those of preceding years. The changes in stage during the dry seasons of 1985-86 were in accord with the rainfall, ground-water changes, and pumpage of those 2 years.

Monthly Change in Lake Stage

The relative influence of climatic factors and pumpage on Lake Parker change in stage is not fully explained in the dry-season change regression (equation 1). The same factors that affect change in lake stage also affect the change in ground-water levels. A technique used in a concurrent study of lake-stage change (M.A. Lopez, U.S. Geological Survey, written commun., 1988) relates the monthly change in lake stage to climatic factors and ground-water level rather than change in ground-water level.

The change in monthly mean lake stage (1966-86) from November through May of the following year was regressed against rainfall, pan evaporation, and water level in the Upper Floridan aquifer. The change in monthly mean stage is estimated by equation 2. The regression R^2 is 0.68 and the standard error of estimate is 0.14 foot.

$$\begin{aligned} \text{Pre.DSTAGE} = {} & 0.062 - 0.752 \times \text{LAGEVAP} \\ & + 0.471 \times \text{RAIN} + 0.0340 \\ & \times \text{AVGW} - 0.0326 \times \text{LAVGW} \\ & - 0.187 \times \text{LAG2EVAP} \end{aligned} \qquad (2)$$

Table 5.—*Summary of simple linear regression of rainfall, pan evaporation, lake stages, ground-water levels, and pumpage as a function of time*

[R^2 is coefficient of determination; YR is calendar year - 1900; EVAP is annual total pan evaporation; WL is annual mean water level, in feet above sea level; PUMP is annual mean pumpage]

Data	Period	Regression equation	R^2	Standard error	Attained significance level
Lakeland annual rainfall, inches	1950-86	RAIN = -0.0174 x YR + 49.46	0.00	9.53	0.906
Bartow annual rainfall, inches	1950-86	RAIN = -0.216 x YR + 67.42	.02	11.18	.218
Lake Alfred annual rainfall, inches	1950-86	RAIN = -0.173 x YR + 62.27	.01	9.54	.248
Plant City annual rainfall, inches	1950-86	RAIN = -0.150 x YR + 63.52	.00	12.07	.426
Lake Alfred annual pan evaporation, inches	1966-86	EVAP = 0.653 x YR + 22.39	.45	4.37	.001
Lake Howard					
Annual mean stage, feet	1950-86	STAGE = -0.023 x YR + 132.40	.07	.78	.057
Annual minimum stage, feet	1950-86	STAGE = -0.033 x YR + 132.22	.12	.89	.021
Annual maximum stage, feet	1950-86	STAGE = -0.022 x YR + 133.03	.06	.79	.086
Lake Mariana					
Annual mean stage, feet	1950-86	STAGE = 0.0045 x YR + 135.72	.00	.59	.625
Annual minimum stage, feet	1950-86	STAGE = 0.0046 x YR + 134.98	.00	.76	.611
Annual maximum stage, feet	1950-86	STAGE = -0.0028 x YR + 136.99	.00	.59	.812
Lake Hamilton					
Annual mean stage, feet	1950-75, 1978-86	STAGE = -0.0483 x YR + 123.40	.16	1.11	.009
Annual minimum stage, feet	1950-75, 1978-86	STAGE = -0.0440 x YR + 121.86	.14	1.10	.016.
Annual maximum stage, feet	1950-75, 1978-86	STAGE = -0.0350 x YR + 124.56	.14	1.35	.014
Crooked Lake annual mean stage, feet	1950-86	STAGE = -0.262 x YR + 134.23	.72	1.74	< .001
ROMP 60 deep well annual mean, feet	1961-86	WL = -0.304 x YR + 80.22	.04	8.10	.164
Tampa well 15 annual mean, feet	1961-86	WL = -0.213 x YR + 78.55	.48	1.66	< .001
Lake Alfred deep well annual mean, feet	1961-86	WL = -0.025 x YR + 128.75	.00	1.01	.357
Sanlon Ranch deep well annual mean, feet	1970-86	WL = 0.489 x YR + 47.24	.20	4.42	.041
Lakeland public-supply pumpage annual mean, million gallons per day	1956-86	PUMP = 0.560 x YR - 24.91	.97	10.83	< .001

where Pre.DSTAGE is the estimate of change in monthly mean stage of Lake Parker, in feet;

LAGEVAP is the previous month total evaporation at the Lake Alfred NWS evaporation pan, in feet;

RAIN is the monthly total rainfall at the Lakeland NWS rain gage, in feet;

AVGW is the average of the monthly mean water levels in the Lake Alfred and ROMP 60 deep wells, in feet above sea level;

LAVGW is the previous month AVGW; and

LAG2EVAP is the second previous month total evaporation at the Lake Alfred NWS evaporation pan, in feet.

The relative correlation of the explanatory variables to the change in monthly mean lake stage expressed as t and $p > |t|$ are as follows: LAGEVAP, $t = -8.90$ and $p > |t| = 0.0001$; RAIN, $t = 7.42$ and $p > |t| = 0.0001$; AVGW, $t = 9.44$ and $p > |t| = 0.0001$; LAVGW, $t = -8.62$ and $p > |t| = 0.0001$; and LAG2EVAP, $t = -2.32$ and $p > |t| = 0.0222$. The relative influence of the explanatory variables varies with the magnitude. This is illustrated by equation 2 computations for four selected months shown in table 6. The two evaporation variables and ground-water levels are grouped to show the sum of the computed partial changes. Evaporation accounts for the largest part of the total change in stage as long as there is little rainfall. In May of 1979, there was enough rainfall to cause a 0.33-foot rise in lake level. The equation 2 estimate of change in stage was +0.36 foot. In this case, the estimated change due to rainfall, +0.63 foot, was greater than the decline due to evaporation, -0.55 foot, and the change due to ground-water levels was +0.22 foot. At the same time, there was a corresponding 2.74-foot rise in ground-water levels. In the other three cases, the change attributable to rainfall varied from 0.00 to 0.11 foot, and lakes levels, as well as ground-water levels, fell.

The use of ground-water levels, the current and the previous month, in equation 2 indicates that the change in ground-water level is indicative of a corresponding change in lake level, as in the dry-season time period (equation 1). The magnitude of the change in ground-water level may be more important than the ground-water levels themselves. In table 6, the 5-foot drop from 88.82 feet in March to 83.82 feet in April of 1967 resulted in the same partial change (-0.05 foot) as the 5.31-foot drop from 93.61 feet in April to 88.30 feet in May of 1986.

The question still to be addressed is what effect the Lakeland well-field pumpage has on change in ground-water levels, which, in turn, influences the change in lake stage. The change in ground-water levels estimated from data at Lake Alfred deep well and ROMP 60 deep well is representative of the regional fluctuation in ground-water level that is influenced by agricultural and industrial pumpage. The exact magnitude of industrial and agricultural ground-water withdrawals that influence the regional fluctuation in ground-water levels was not determined during this study, but an approximate comparison with the Lakeland municipal supply withdrawals can be made from a water-use summary using data up to 1981 (Duerr and Sohm, 1983). Industrial ground-water use in Polk County gradually declined from 270.4 Mgal/d in 1975 to 187.4 Mgal/d in 1981. Irrigation ground-water use varied from 156.1 Mgal/d in 1970 to 51.2 Mgal/d in 1980. Irrigation water use varies seasonally as well as annually. In 1981, water use was about 240 Mgal/d during April, May, and June and dropped to about 10 Mgal/d in July, August, and September.

In view of the seasonal variability and distribution of agricultural pumpage and the absence of readily available data of regional water use, further attempts to relate the change in ground-water levels to Lakeland municipal water-supply pumpage was not warranted. As more data on regional water use become available, a transient ground-water model may be used to determine the relative effect of municipal water-supply pumpage.

SUMMARY

The stage of Lake Parker in Lakeland, Fla., declined to (37-year) record lows in 1985-86. City officials and local residents were concerned that the low stages may be the result of a long-term declining trend specific to Lake Parker. This report analyzes existing hydrologic data to determine if long-term trends exist in Lake Parker stage that are different than trends in other lake-stage data, rainfall, evaporation, pumpage, and ground-water levels. The relation between Lake Parker stage data and the other hydrologic data also were analyzed.

No trends significant at the 10-percent level were indicated in any of several Lake Parker stage variables for 1950-86, which included annual mean, minimum,

Table 6.—*Computation of change in Lake Parker stage by equation 2 for four selected months*

Pre.DSTAGE = 0.062 - 0.752 x LAGEVAP + 0.471 x RAIN + 0.0340 x AVGW
- 0.0326 x LAVGW - 0.187 x LAG2EVAP

Date	Explanatory variable	Observed value	Computed partial change (feet)		Estimated change in stage (feet)
April 1967 (Recorded change in stage, -0.40)					
	RAIN	0.00	0.00		
	LAGEVAP	.53	- .40	-0.46	
	LAG2EVAP	.33	- .06		
	AVGW	83.82	2.85	- .05	
	LAVGW	88.82	-2.90		
		Regression constant		.06	-0.45
May 1979 (Recorded change in stage, +0.33)					
	RAIN	1.34	.63		
	LAGEVAP	.60	- .45	- .55	
	LAG2EVAP	.51	- .10		
	AVGW	89.95	3.06	.22	
	LAVGW	87.21	-2.84		
		Regression constant		.06	+ .36
December 1985 (Recorded change in stage, -0.15)					
	RAIN	.24	.11		
	LAGEVAP	.39	- .29	- .39	
	LAG2EVAP	.54	- .10		
	AVGW	95.72	3.25	.12	
	LAVGW	95.93	-3.13		
		Regression constant		.06	- .10
May 1986 (Recorded change in stage, -0.72)					
	RAIN	.05	.02		
	LAGEVAP	.77	- .58	- .69	
	LAG2EVAP	.57	- .11		
	AVGW	88.30	3.00	- .05	
	LAVGW	93.61	-3.05		
		Regression constant		.06	- .66

and maximum stages; low-stage duration values of 1 to 183 days; and seasonal and annual change in stage. The two analytical methods used to determine the existence of trends – nonparametric Kendall tau test and linear regression of stage variables against time – were consistent in indicating no trend. Time series plots of Kendall tau values for various starting or ending years of data collection show that Lake Parker annual minimum stage data for 1950-80 would indicate a significant increasing trend, and data for 1980-86 would indicate a significant decreasing trend.

Data from four other lakes, four ground-water sites, four rainfall sites, Lakeland public-supply ground-water pumpage, and one pan evaporation site also were analyzed by the two trend-determination methods. Annual mean stage data from the lakes indicate declining slope estimators significant at the 10-percent level at Lake Howard (-0.03 ft/yr), Lake Hamilton (-0.06 ft/yr), and Crooked Lake (-0.27 ft/yr). Data for Lake Mariana indicated no significant trends. Annual mean water levels at Tampa deep well 15 indicated a -0.25-ft/yr slope estimator significant at the 0.01-percent level. No significant trends were indicated for water levels at ROMP 60 deep well or Lake Alfred deep well. The significant upward trend of water levels of Sanlon Ranch deep well may be indicative of a shorter period of record (1970-86) rather than a departure from the other three deep well records. Both pumpage and pan evaporation indicated increasing trends significant at the 0.01-percent level.

Multiple linear regression of Lake Parker change in stage for annual dry seasons (November through May) against change in ground-water levels, rainfall, and pumpage provided the regression of best fit (R^2 = 0.90 and standard error = 0.24 foot).

Dry-season (November-May) regression analysis of monthly change in Lake Parker stage indicated that evaporation usually had the largest effect on change in stage. The explanatory variables in order of significance are: pan evaporation the previous month, rainfall the current month, ground-water level the current month, ground-water level the previous month, and pan evaporation the second previous month. The regression R^2 is 0.67, and standard error is 0.14 foot. The influence of rainfall is greater only for months that rainfall exceeded pan evaporation. The regression coefficient for ground-water level of the current month was positive and slightly greater than the negative coefficient for ground-water level of the previous month. The change in ground-water level may be more highly correlated to change in lake stage than the elevation of the water levels themselves.

The changes in ground-water levels estimated from Lake Alfred deep well and ROMP 60 deep well are representative of the regional fluctuation in ground-water levels that are influenced by agricultural and industrial pumpage. Industrial ground-water use in Polk County declined from 270.4 Mgal/d in 1975 to 187.4 Mgal/d in 1981. Irrigation ground-water use varied from 156.1 Mgal/d in 1970 to 51.2 Mgal/d in 1980. In view of the seasonal variability and distribution of agricultural pumpage and the absence of readily available regional water-use data, further attempts to relate the change in ground-water levels to Lakeland water-supply pumpage were not warranted.

REFERENCES

Buono, Anthony, Spechler, R.M., Barr, G.L., and Wolansky, R.M., 1979, Generalized thickness of the confining bed overlying the Floridan aquifer, Southwest Florida Water Management District: U.S. Geological Survey Water-Resources Investigations Open-File Report 79-1171, 1 sheet.

Duerr, A.D., and Sohm, J.E., 1983, Estimated water use in southwest Florida, 1981, and summary of annual water use, 1970, 1975, and 1977-81: U.S. Geological Survey Open-File Report 83-45, 75 p.

Dyer, Riddle, Mills and Precourt, Inc., 1986, Lake Parker information and briefing document: Engineer's report prepared for the City of Lakeland, Florida, 61 p.

Hirsch, R.M., and Slack, J.R., 1984, A nonparametric trend test for seasonal data with serial dependence: Water Resources Research, v. 20, no. 6, p. 727-728.

Hirsch, R.M., Slack, J.R., and Smith, R.A., 1982, Techniques of trend analysis for monthly water-quality data: Water Resources Research, v. 18, no. 1, p. 107-121.

Kendall, Maurice, 1975, Rank correlation methods: London, Charles Griffin and Co., Ltd, 202 p.

Riggs, H.C., 1968, Some statistical tools in hydrology: U.S. Geological Survey Techniques of Water-Resources Investigations, Book 4, Chap. A1, 39 p.

Stieglitz, E.H., 1986, Estimated water use in the Southwest Florida Water Management District, 1986: Southwest Florida Water Management District, November 1986, 57 p.

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